

A Narrative Review of Alternate Gait Training Using Knee-ankle-foot Orthosis in Stroke Patients with Severe Hemiparesis

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ABSTRACT. Impairments resulting from stroke lead to persistent difficulties with walking. Subsequently, an improved walking ability is one of the highest priorities for people living with stroke. The degree to which gait can be restored after a stroke is related to both the initial impairment in walking ability and the severity of paresis of the lower extremities. However, there are some patients with severe motor paralysis and a markedly disrupted corticospinal tract who regain their gait function. Recently, several case reports have described the recovery of gait function in stroke patients with severe hemiplegia by providing alternate gait training. Multiple studies have demonstrated that gait training can induce “locomotor-like” coordinated muscle activity of paralyzed lower limbs in people with spinal cord injury. In the present review, we discuss the neural mechanisms of gait, and then we review case reports on the restoration of gait function in stroke patients with severe hemiplegia.

Key words: Knee-ankle-foot orthosis (KAFO), Stroke, Gait, Hemiparesis, Inverted pendulum

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Globally, the estimated total number of stroke patients was 33 million in 2010¹⁾. Stroke is the second leading cause of death and a major contributor to disability worldwide²⁾. Impairments resulting from stroke often lead to persistent difficulties with walking. Subsequently, an improved walking ability is one of the highest priorities for people living after a stroke³⁾. In addition, walking ability has important health implications in providing protective effects against secondary complications that are common after a stroke, such as heart disease or osteoporosis³⁾.

The degree to which gait can be restored after a stroke is related to both the initial impairment in walking ability and the severity of paresis of the lower extremities^{4,8)}. Wan-

del et al.⁷⁾ reported that only 21% of stroke survivors with lower limb paralysis regained the ability to walk. In other words, there is no doubt that severe paralysis of the lower limbs and muscle weakness are factors closely related to the ability to walk. However, there are patients with severe motor paralysis and a markedly disrupted corticospinal tract who regained their gait function^{9,10)}. In addition, Sivaramakrishnan and Madhavan¹¹⁾ reported that there was no association between transcranial magnetic stimulation-induced tibialis anterior and rectus femoris motor evoked potentials, which are neurophysiological parameters of lower limb function, and walking speeds. Indeed, many patients have regained gait function even after experiencing severe hemiparesis¹²⁻¹⁶⁾. Recently, several case reports¹²⁻¹⁴⁾ described the restoration of gait function in stroke patients with severe hemiplegia after the provision of alternate gait training (AGT). Multiple studies have demonstrated that gait training can induce “locomotor-like” coordinated muscle activity of the paralyzed lower limbs in people with spinal cord injury¹⁷⁻¹⁹⁾.

In the present narrative review, we will discuss the

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neural mechanisms of gait, and then review case reports on the restoration of gait function in stroke patients with severe hemiplegia.

Alternative Gait Training Using Knee-ankle-foot Orthosis (KAFO) for Stroke Patients with Severe Hemiplegia

1) Neural mechanisms of gait, and ideas for restoring gait in stroke patients with severe hemiplegia.

Decerebrate cats, with an absence of the forebrain, can walk, trot and gallop. When decerebration occurs at precollicular-postmammillary level, the cat initiates locomotion by electrical or chemical stimulation applied to the mesencephalic or midbrain locomotor region²⁰⁻²³. To date, three locomotor regions have been identified in animals: the midbrain locomotor region in the mesopontine tegmentum, the subthalamic locomotor region, and the cerebellar locomotor region in the mid-part of the cerebellum²⁴. Human imaging has demonstrated that the organization of these supraspinal locomotor centers was preserved during the transition to bipedal locomotion in humans²⁵.

The regulation of human upright posture and locomotion is based on the finely tuned coordination of muscle activation between the two legs¹⁷. For example, when a disturbance causes an initiation or prolongation of the swing phase on one side, the stance phase of the contralateral leg compensates accordingly, in both human infants and cats¹⁷. Unilateral leg displacement during stance and gait evoke a bilateral response pattern with similar short (i.e., spinal) onset latencies on both sides¹⁷. This interlimb coordination is necessary to keep the body's center of gravity over the feet^{17,26}.

In cats, there are two main sources of afferent input that lead to rhythm entrainment and/or resetting of locomotor activity¹⁷. Such input can either block or induce switching between the alternating flexor and extensor locomotor bursts. One afferent input source is related to hip position, and the other is related to load^{17,27}. For example, for the initiation of the swing phase, the significance of hip position was essential for human infant stepping, similarly to what was described for the cat with chronic spinal cord transection¹⁷. Furthermore, in previous studies, load receptor input for the regulation of stance and gait was important for cats²⁸ and humans²⁹. It was assumed that this effect was mediated by group Ib afferent input³⁰.

Further studies have indicated that even in completely paraplegic patients, a locomotor pattern can be evoked by bilateral alternating stepping^{31,32}. In these studies, load receptor input was essential for leg muscle activation during stepping movements¹⁷. Habli and Dietz¹⁹ found that load- and hip-joint- related afferent input is of crucial importance during locomotor training, as it leads to appropriate leg muscle activation, and thus increases the efficacy of reha-

ilitative training. According to previous reports, gait function is influenced by the following: the control system of voluntary function, such as the corticospinal tract; the control system of involuntary motor function, such as the mesencephalic-reticulospinal neuron; and the central pattern generator in the spinal cord³³⁻³⁵.

In patients with spinal cord injury, alternate stepping movements with afferent input from load receptors induce a patterned leg muscle activation similar to that induced in healthy subjects^{17,18}. In other words, these inputs induce lower limb muscle activity in patients with difficulties in voluntary lower limb movement. Therefore, we hypothesized that earlier improvement of gait function could be achieved by providing an alternate gait pattern for patients with severe hemiplegia, because it facilitates the afferent load and proprioceptive receptor inputs. In particular, afferent information from both bilateral hip joints seems to be essential for the generation of locomotor-patterned leg muscle activation; however, unilateral stepping movements lead to inadequate leg muscle activation^{17,18}. Indeed, patients with severe hemiparesis commonly have poor lower limb stability on the paretic side and difficulty in walking without lower limb support. To achieve good stability, patients benefit from strong external support, such as a KAFO, which provides both stability and enables the ankle to perform alternate stepping. We hypothesized that patients may regain gait function earlier if gait training is implemented using a KAFO. We defined AGT as walking with alternate large hip flexion and extension when using a KAFO with an oil damper ankle hinge.

2) Technique for providing AGT using a KAFO with an oil damper ankle hinge

A KAFO for use in AGT has a ring lock hinge for the knee joint and an oil damper hinge for the ankle joint^{36,37}. (Fig. 1) The hinged oil damper can resist plantarflexion during swing, and produce plantarflexion after heel contact³⁶⁻³⁸. Therefore, the loading response period is properly constructed because the first rocker function is maintained³⁶⁻³⁸. Moreover, using a KAFO with an oil damper ankle hinge has other merits as it matches the inverted pendulum movement that is observed in normal walking (Fig. 2A, B) because the hinged oil damper does not hinder dorsiflexion³⁶⁻³⁸. An inverted pendulum model of the stance leg is crucial for effective, economical, and stable ambulation in biomechanical features³⁹. AGT is provided by a physical therapist (Fig. 2C), and if AGT cannot be performed with therapists providing external assistance, step training is utilized for each of the affected and unaffected lower limbs. AGT is then started shortly after step training. After resolution of the problem of knee instability, an ankle-foot orthosis (AFO) is used. Before transitioning from KAFO to AFO (known as "cutting down"), we confirm that subjects can walk with an alternate gait pattern with AFO alone.

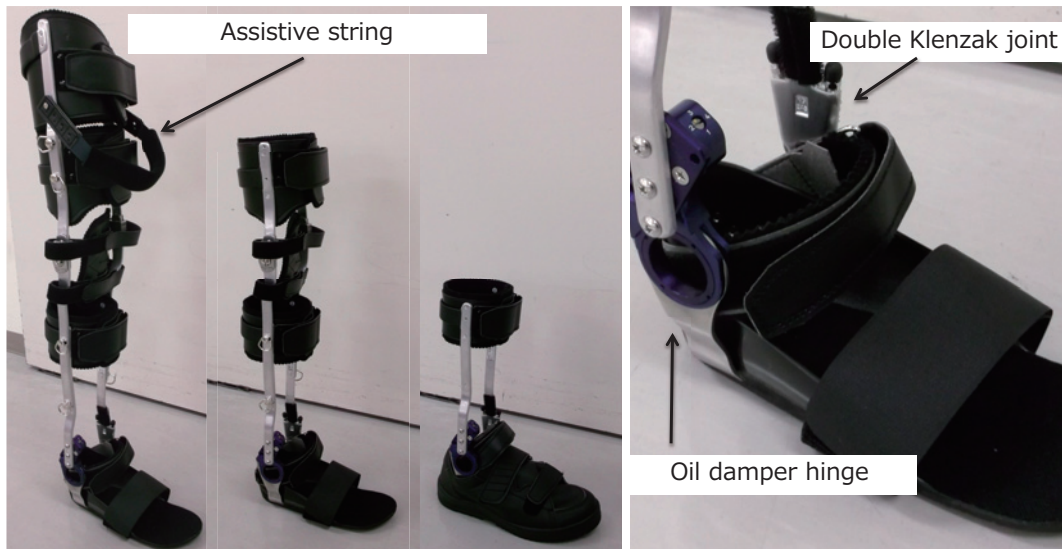


Fig. 1. A knee-ankle-foot orthosis with an oil damper ankle hinge.

The hinged oil damper can resist plantarflexion during swing and promote adequate plantarflexion after heel contact.

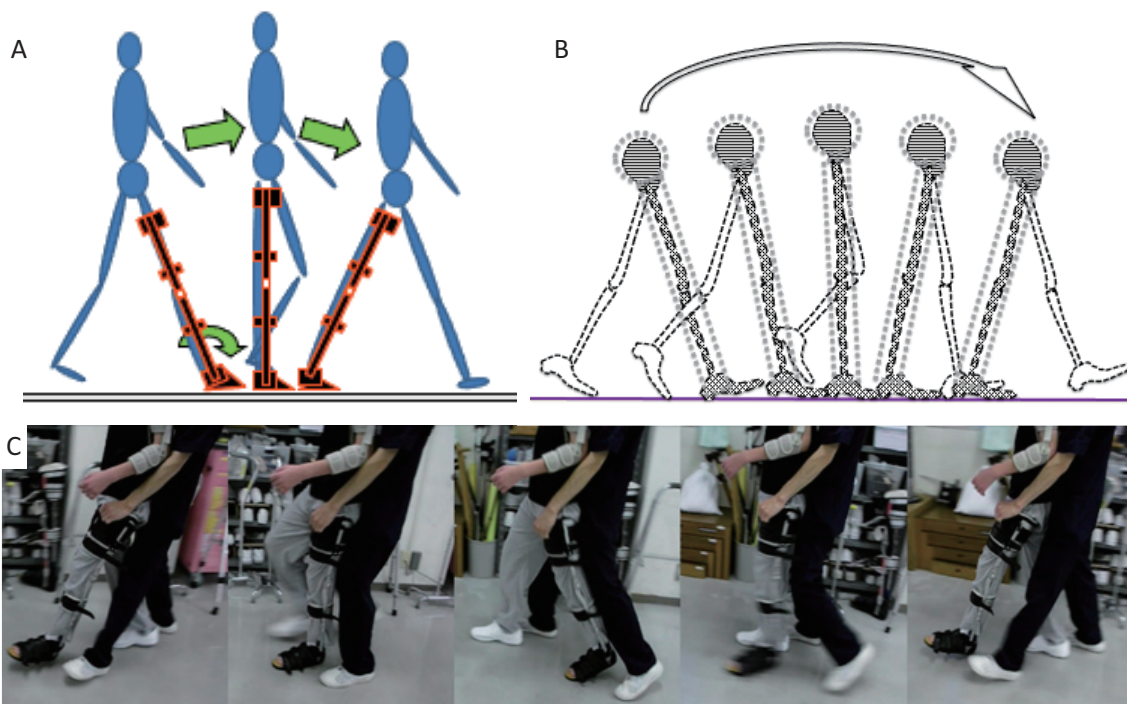


Fig. 2. Alternate gait pattern using knee-ankle-foot orthosis with an oil damper ankle hinge that matches the inverted pendulum model.

A: Alternate gait pattern using knee-ankle-foot orthosis with an oil damper ankle hinge

B: The inverted pendulum model

C: Alternate gait pattern using knee-ankle-foot orthosis with an oil damper ankle hinge with external assist by physiotherapist

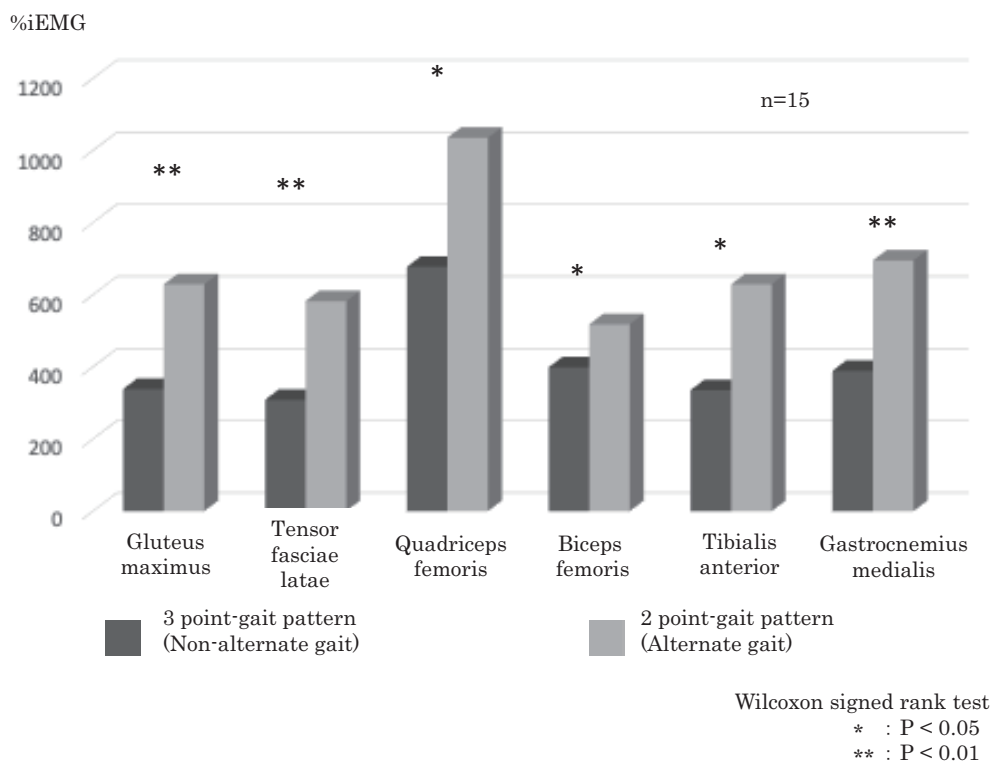


Fig. 3. Electromyography results

Integrated electromyography revealed that all six muscles had more increased muscle activity in the affected side lower limb during the stance phase of the 2-point gait pattern than of the 3-point gait pattern.

A Comparative Study of the Effect of AGT Using a KAFO

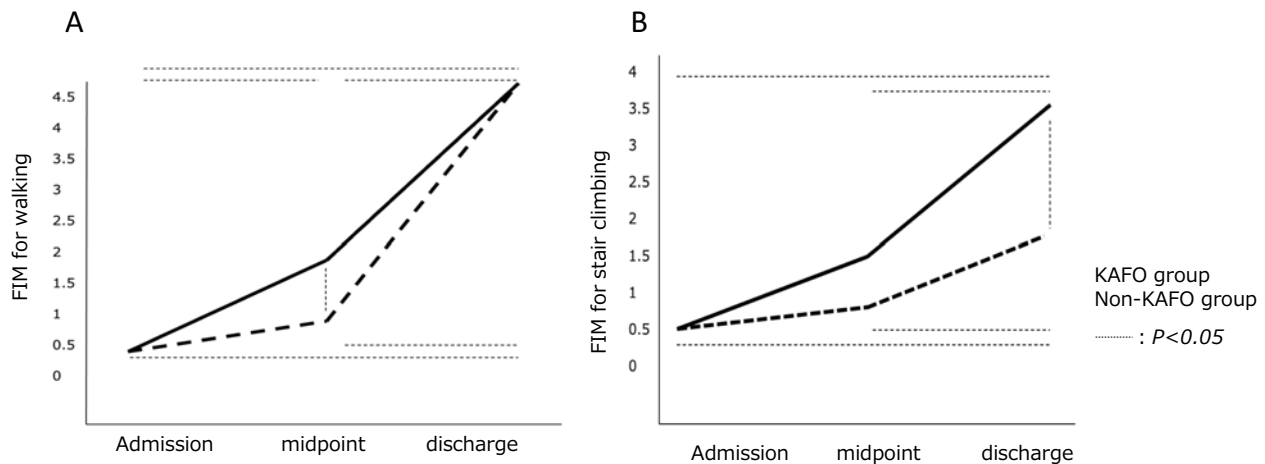
1) *Muscle activity during AGT; the differences in lower leg muscle activity between 2-point gait (AGT pattern) and the conventional 3-point gait patterns (defined as walking with a stride length of the non-affected leg not exceeding that of the affected leg).*

We have investigated⁴⁰⁾ differences in lower limb muscle activity during two gait patterns—2-point gait without a cane and 3-point gait with a cane—in 12 stroke patients. All 12 patients required KAFOs due to severe hemiparesis when walking. When performing the 2-point gait training, the patients would step the unaffected foot in front of the affected foot with assistance provided by a physical therapist. In contrast, when carrying out the 3-point gait training, patients would step the unaffected foot to the lateral side of the affected foot using the cane with slight assistance by the physical therapist. The muscle activities were measured by electromyogram in the tibialis anterior, gastrocnemius medialis, biceps femoris, quadriceps femoris, gluteus maximus, and tensor fasciae latae muscles of the affected lower limb. Integrated electromyography revealed that all six muscles had increased muscle activity during the stance phase of the 2-point gait pattern than of the 3-point gait pattern (Fig. 3). In severe hemiparetic patients, 2-point gait

training may be more effective in facilitating muscle activity of the paretic lower limb than 3-point gait training.

2) *AGT with a KAFO to support earlier walking independence*

We have previously reported⁴¹⁾ the effects of physical therapy with an early prescription of KAFO during the course of recovery of walking and stair climbing functions evaluated using Functional Independence Measures (FIM). Eight patients with post-stroke hemiparesis, who had been prescribed a KAFO and had received AGT during their acute hospital stays (the KAFO group), and 20 patients who had not been prescribed a KAFO (the non-KAFO group), were recruited. All patients in the non-KAFO group had similar characteristics to those in the KAFO group on admission; age, length of hospitalization, severity of hemiparesis, duration between stroke onset and admission to the convalescent rehabilitation ward, walking function, and stair climbing function. We compared the time course of recovery of walking and stair climbing functions between the KAFO and non-KAFO groups by using FIM at admission, midpoint of the hospital stay, and discharge from the rehabilitation ward. FIM for walking and stair climbing gradually improved in both groups. However, walking function improved earlier in the KAFO group than in the non-KAFO group (Fig. 4A). Furthermore, the stair climbing function at



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Fig. 4. The time course of recovery of walking and stair climbing functions in the KAFO and non-KAFO groups evaluated using FIM at admission, midpoint of hospital stay, and discharge.

discharge was significantly better in the KAFO group than in the non-KAFO group (Fig. 4B). Therefore, physical therapy using an early-prescribed KAFO might be effective for improving walking and stair climbing functions in post-stroke patients with severe hemiparesis.

Case Reports

1) Gait restoration in a patient who required full assistance to walk at 6 months after stroke onset

Kadowaki et al.¹²⁾ tried to restore the gait function in a patient with severe stroke hemiparesis who required full assistance to walk 6 months after stroke onset. This patient was a woman in her 50s who had suffered subarachnoid and intracerebral hemorrhages. Her Brunnstrom motor function was stage II in the upper limbs and fingers, and II-III in the lower limbs.

The patient underwent physical therapy in the Kai-fukuki rehabilitation (convalescent) ward and received gait training using a soft knee brace and a soft bandage between 75 and 176 days of stroke onset. At six months post-stroke, any improvement in motor paralysis was unlikely. Nevertheless, we assumed that her gait function could be improved if lower limb muscle activity was induced by providing AGT.

Initially, we provided AGT using a soft knee orthosis and an AFO. However, the inverted pendulum movement could not be constructed because of the bent knee of the affected side during the stance phase. We therefore decided to make a KAFO for the patient. Figure 5A shows the gait pattern at 3 weeks after admission. Figure 5B shows a trial transition from the KAFO to the AFO. In this trial, the knee joint was observed as too bent in the AFO, so we continued gait training using the KAFO. Figure 5C shows the patient's gait at discharge, and Figure 5D shows the gait at home following hospital discharge. The patient achieved re-

markable recovery with AGT; from being unable to walk at 6 months after stroke onset to eventually being able to walk independently.

2) Gait reconstruction in a patient with complete damage to the corticospinal tract.

We (Tsujimoto et al.¹³⁾) previously reported a case of gait reconstruction in a young patient with large right frontal lobe cortical hemorrhage due to a ruptured arteriovenous malformation (AVM). The lesion extended from the central precentral gyrus to the subcortical region of the postcentral gyrus (Fig. 6A). It was not possible to visualize the corticospinal and sensory tracts on diffusion tensor tractography (Fig. 6B). The patient in fact showed severe hemiparesis and severe sensory disturbance. The patient's functional ambulation category (FAC) went from 5 (fully independent) before the AVM ruptured to FAC 0 (unable to walk).

The patient's knee was excessively bent and showed an extension thrust pattern (Fig. 7A). For restoration of his gait function, a KAFO with the oil damper ankle hinge was used, and AGT was provided. Initially, the patient was assisted by a physiotherapist (Fig. 7B), with the assistance gradually reduced (Fig. 7C). A previous report⁹⁾ stated that gait reconstruction is possible even when the corticospinal tract is completely damaged. In this young patient, physical therapy was started on Day 34 after the AVM rupture, and his walking ability gradually improved, reaching 58.8 m/min as a maximum walking speed on Day 113 (Fig. 7D). At the same time, the KAFO was switched over to an AFO, and his gait training continued. After transfer to a convalescent hospital, the patient was eventually able to walk independently both indoors and outdoors.

Conclusions

In the current narrative review, we introduced AGT



Fig. 5. The restoration of gait function in a stroke patient with severe hemiparesis who required external assistance for gait 6 months after stroke onset.

1. Initial contact; 2. Loading response; 3. Mid stance; 4. Terminal stance

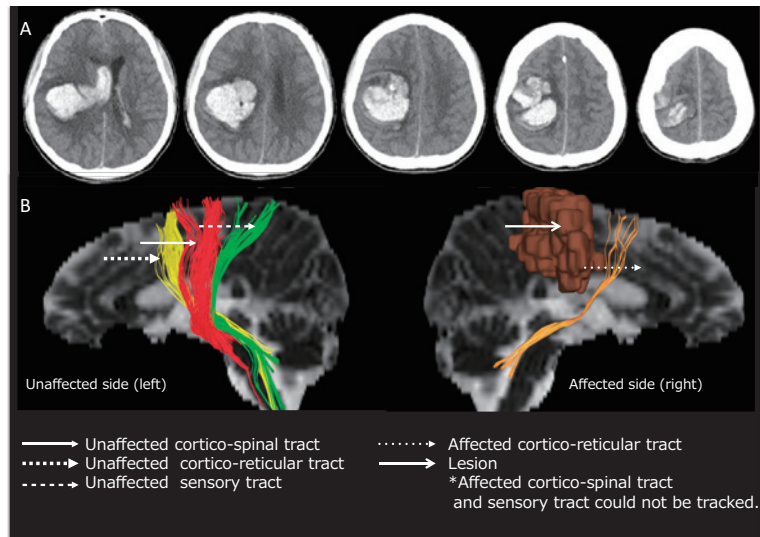


Fig. 6. Brain imaging of intracranial hemorrhage due to ruptured arteriovenous malformation.

A: Computed tomography

B: Diffusion tensor tractography

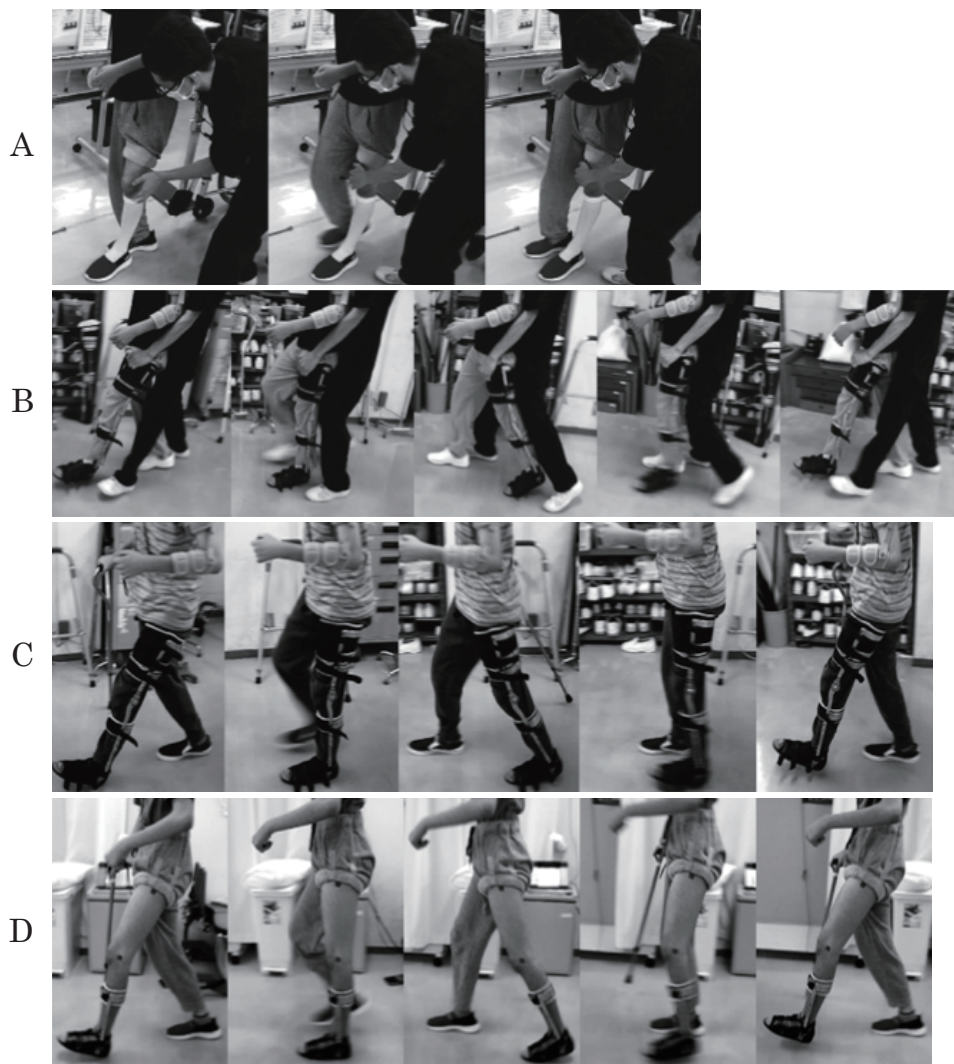


Fig. 7. The restoration of gait function in a stroke patient with severe hemiparesis with complete disconnection of the corticospinal tract and sensory tract on the affected side.

using a KAFO for restoration of gait function in stroke patients with severe hemiparesis. We believe that AGT with a KAFO can benefit stroke patients with severe hemiparesis as they may achieve earlier improvements in gait ability. Neurological physical therapists should be encouraged to use this approach for restoration of gait function in such patients. However, the effect of AGT is not fully elucidated, and there are very few reports on this subject, all of which are written in Japanese. Further study is required to validate the effect of AGT with a KAFO.

Conflict of Interest: The authors declare that there are no conflicts of interest.

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